9.4.3 Earthwork Design

Earthwork design includes the following:

- clearing and grubbing,
- additional clearing and grubbing,
- removal of structures and obstructions,
- excavation and embankment,
- rock blasting,
- watering,
- earthwork geotextiles,
- structure excavation and backfill for selected major structures,
- structures excavation and backfill,
- drainage layer,
- roadway obliteration,
- linear grading, and
- subgrade stabilization.

9.4.3.1 Clearing and Grubbing

Clearing widths should extend 1.5 m (5 ft) beyond the outer limit of slope rounding for cuts and 1.5 m (5 ft) beyond the toe of fill. Additional clearing and grubbing includes the following:

- additional clearing or selective thinning of vegetation at the top of high cuts,
- additional clearing for scalloping and vistas to improve visual appearance,
- additional clearing required for the accommodation of utilities, and
- additional clearing to allow for southern exposure to assist in melting snow in high elevations.

Clearing and grubbing widths may be limited under the following situations:

- decreased clearing allowance in sensitive areas (e.g., National Parks, areas where the preservation of existing vegetation is critical); and
- decreased clearing because of limited right-of-way.

Clearing and grubbing quantities are normally computed using CADD, except for isolated areas of special clearing outside the normal section. Clearing quantities are usually not computed until the earthwork runs are completed.

9.4.3.2 Removal of Structures and Obstructions

This work consists of the removal and disposal of all buildings, fences, structures, old pavements, abandoned pipelines and other obstructions that cannot remain in place.

9.4.3.3 Classification of Roadway Excavation

Classification of roadway excavation for design purposes includes the following types:

1. **Common Material**. Common material is largely earth or earth with detached boulders less than 0.5 m^3 (0.5 yd^3).

2. **Rippable Rock**. Rippable rock refers to material ready for excavating after it is loosened by a ripper.

3. **Solid Rock**. Solid rock includes hard rock in place, ledge rock and boulders requiring drilling and blasting equipment for removal. Any blasting work will be performed according to the rock blasting section specifications.

In addition to the excavation for the constructions of roadways, there may be excavation for drainage ditches, culverts, bridges and grade separation structures. Still another type excavation includes dredging operations for hydraulic fills.

Using data furnished by the Geotechnical Unit, the designer must check the characteristics of the material to be excavated or placed in embankments. The excavation used for embankments will range from rock to earth and have shrink/swell factors assigned for design purposes.

9.4.3.4 Shrink and Swell Factors

Roadway excavation, however classified, is commonly but not always measured in the original, undisturbed position. The specifications must carefully state the place and method of measurement because almost all materials change volume in their movement from cut to fill.

Excavated earth will expand beyond its original volume in the transporting vehicle but will shrink below the excavated volume when compacted into the fill. To illustrate, 1 m^3 (1 yd^3) of earth in the cut may use 1.25 m^3 (1.25 yd^3) of space in the transporting vehicle, and finally occupy only 0.65 m^3 to 0.85 m^3 (0.65 yd^3 to 0.85 yd^3) in the embankment. This, of course, depends on its original density and the compactive effort applied. This difference between the original volume in a cut and the final volume in a fill is the shrink.

Excavated rock placed in a fill occupies a larger volume. This change in volume is the swell. When the voids in the rock embankment become filled with earth or other fine material, the volume in the fill will just about equal the combined volumes in the two source locations.

For light soil excavation and for fills constructed on swampy ground subject to settlement, the shrink may range from 20 to 40 percent or even greater. For moderate soil excavation, the shrink ranges from ten to 25 percent. For heavy soil excavation with deep cuts and fills, expect a range of approximately 15 percent shrink to five percent swell. Shrink generally includes the slight waste in transporting material from cut to fill and the loss for material which escapes beyond the toe of slopes.

A swell of five to 25 percent is anticipated in rock excavation depending upon the proportion of solid rock and upon the size of the rock placed in the fill.

When available, the design should incorporate actual field shrink and swell factors for like material used on adjoining projects.

The shrink factor is determined by Equation 9.4(3):

$$\text{Shrink Factor} = \frac{1}{1 + \frac{\%\ \text{shrinkage}}{100}} \qquad \text{Equation 9.4(3)}$$

Thus, if the percent of shrink is 25 percent, the shrink factor would be:

$$\frac{1}{1 + \frac{25}{100}} = \frac{1}{1.25} = 0.8$$

The swell factor for rock excavation is determined by Equation 9.4(4):

$$\text{Swell Factor} = 1 + \frac{\%\ \text{swell}}{100} \qquad \text{Equation 9.4(4)}$$

Thus, if the percent of swell is 25 percent, the swell factor would be the following:

$$1 + \frac{25}{100} = 1.25$$

See Chapter 6, Exhibit 6.4F for additional information on shrink/swell factors used for commonly specified materials.

The shrink/swell factors are applied to the excavation quantities to arrive at the adjusted quantities.

Settlement results in shrinkage, but one is not directly proportional to the other. Do not confuse shrink with subsidence. Subsidence is settlement of the entire embankment due to unstable foundation conditions (e.g., placing heavy fill on swampy soil).

9.4.3.5 Design Cut and Fill Slopes

The design of cut and fill slopes depends upon the characteristics of the material. The designer should refer to the Geotechnical Report for recommended slope ratios. (See Section 9.4.1.)

9.4.3.6 Slides

When the Geotechnical Report identifies potential areas for slides, the earthwork excavation quantities may require adjustment to cover potential slide removal. Provisions to dispose of excess slide material are necessary.

9.4.3.7 Balancing Earthwork

The earthwork is balanced when the volume of excavation (with the appropriate allowances made for shrink and swell) equals the volume of embankment. The designer shall consider the quantity of subexcavation removed and disposed of and the quantity of topsoil reserved for slopes in the balance quantities.

It frequently happens that the material from the adjacent cuts is not sufficient to make the intervening fill. In this case, material is borrowed from outside the construction limits.

When there is an excess of excavated material, it may be necessary to dispose of the material. Instead of long hauls, it may be more economical to dispose of the material by widening shoulders or placing the material in disposal areas than to pay hauling costs.

If the earthwork is not in balance, the designer should try to adjust grade line or centerline so it is in balance. When a balanced project is not practical or desirable, the designer either disposes of excess material or borrows material to obtain a balance. Designated disposal or borrow areas require clearance for proper ownership, rights-of-use, environmental concerns and applicable permits.

Waste areas for the disposal of excess material and/or borrow areas should be shown on the plans.

The Geotechnical Unit should evaluate the sites and provide recommendations on classification of borrow material or slopes and depth of embankment allowed in disposal sites. Appropriate environmental considerations apply to reclamation or rehabilitation plans for the disposal sites.

The designer can use the added quantities feature of CADD to add or subtract cut or fill from the quantities computed for the roadway.

9.4.3.8 Haul

Haul consists of transporting material from its original position to its final location. The cost to haul material is required to estimate the unit price of various items of work.

Haul costs are based on hauling one cubic meter (cubic yard) of material a distance of 1 km (1 mi) or 1 metric ton (1 ton) of material a distance of 1 km (1 mi) using the shortest practical route. Haul costs are generally based on a rate per unit of time for the hauling equipment multiplied by the actual time needed to move the material. This is quite simple when calculating costs to haul from crusher sites to the middle of a project. It becomes more complicated when estimating costs to haul material between balance points on a grading project. The use of a mass diagram as described below will provide the quantity of haul within balance points as well as other helpful information. It is up to the designer to determine a cost estimate based on historical data and the equipment needs, and work rates to move the material.

9.4.3.9 Mass Diagram

A mass diagram is a continuous curve showing the accumulated algebraic sum of the excavation (cuts [+]) and embankment (fills [–]) from some initial station to any succeeding station. The points of the mass curve are plotted to a horizontal scale of distances (same as profile) and a vertical scale of cubic meters (cubic feet) (e.g., 1 mm = 50 m^3 (1 in = 1000 yd^3)).

The designer can prepare a mass diagram using CADD to arrive at haul quantities for cost estimating purposes. The steps necessary to generate and interpret mass diagrams are explained in Part IX, Chapter 15 of the GEOPAK *Users Manual*.

The characteristic properties of a mass diagram (or curve) are as follows:

- The ordinate at any point on the mass curve represents the cumulative cubic meter (cubic feet) to that point on the profile.
- Within the limits of a single cut, the curve rises from left to right. Within the limits of a single fill, it falls from left to right.
- Sections where the cumulative cubic meter (cubic feet) changes from cut to fill correspond to a maximum. Sections where the cumulative cubic meter (cubic feet) changes from fill to cut correspond to a minimum.
- Any horizontal line cutting off a loop of the mass curve intersects the curve at two points. Within this area the cut is equal to the fill (adjusted for shrinkage). This line is called a balance line.
- The loops that convex upward show that the haul from cut to fill is to be in one direction. Loops that concave upward indicate a reverse direction of haul.

A mass diagram can assist in balancing cuts and fills and showing the best distribution of materials. The mass diagram shows the most economical procedure for the disposing of excavated material. It also shows which part to move forward or backward, and whether borrowing and wasting are advisable. It presents a graphic picture of the distribution of materials and the haul involved in the placement.

9.4.3.10 Computing Structural Excavation Quantities

To determine the quantity of structure excavation for pipe culverts, box culverts or other drainage structures, plot a cross section at the location of the structure, plot the roadway template and draw the grade line of the structure. Calculate the average end area and compute the excavation quantity.

Round the structure excavation for each pipe to the nearest cubic meter (cubic yard) and show this quantity on the Drainage Summary Sheet of the plans.

Structure excavation for foundation trenches for riprap, walls, etc., is calculated by average end areas and lengths and is shown on the plans where the work is to take place.

9.4.3.11 Subgrade Treatment

The Geotechnical Report should identify the location of and propose a solution for any subgrade problems. The following applies:

- subexcavate unsuitable subgrade materials and use special backfill;
- stabilize poor quality subgrade materials in-situ with additives (e.g., lime, fly ash, cement);
- place special subgrade topping material;
- use geotextiles to increase support values;
- install special drainage systems; or
- a combination of any of the above.

The designer is responsible for incorporating the appropriate corrective measures into the design and for including any Special Contract Requirements and special drawings into the PS&E package.

9.4.3.12 Roadway Obliteration

Roadway sections no longer needed for traffic and located outside the cuts or fills are often obliterated. Obliteration consists of restoring the ground to approximately the original contour to produce a pleasing appearance by forming naturally rounded slopes.

The designer should evaluate the obliteration work and consider salvaging existing base rock or other surfacing materials for incorporation into the new construction.

Material from the old roadway used in the new roadway, and material from the new roadway used in obliteration of the old roadway, is paid for under Section 204 or other Sections of the *Standard Specifications*. The designer may obtain topsoil or other recyclable materials in this manner.

9.4.3.13 Design Steps Using CADD

The guides listed below represent the more commonly used technique. The designer should refer to the *CADD Manual* for details in the preparation of input to obtain specific output data.

Obtain the roadway template, cross-section and other miscellaneous design information from the approved standards for input into CADD. See Section 9.4.1.7.

1. Refer to Section 9.4.1 for guidelines on the following topics:

   - aesthetic consideration in highway design,
   - horizontal and vertical alignment relationship,
   - establishing control points,
   - horizontal alignment, and
   - vertical alignment.

   Usually more than one horizontal or vertical alignment is studied. These studies deal with cost, alignment, safety, encroachment on waterways, right-of-way, aesthetics, maintenance and operation. After the completion of the studies, one line is selected for further enhancement and refinement of design.

2. Position the design line over the survey data provided using the controls and guidance mentioned above.

3. Compute the station and coordinates of curve and PI points, bearings, tangent lengths, curve lengths, radii, tangent distances and delta angles using the CADD Horizontal Alignment Program. Spiral functions are computed for spiraled curves.

   Unless otherwise required, bearings computed to the nearest minute are acceptable. The arc definition for curves is used with few exceptions.

4. Obtain a plot of the design profile.

5. Using recommended design speed for the route, prepare a progressive listing of each tangent/curve and determine the standard safe speed from charts found in the *Green Book*. Then adjust this standard safe design speed for local requirements (e.g., snow and ice conditions, relatively steep grades) and specific requirements of the cooperating agency.

   The CADD Program can automatically assign a superelevation rate and runoff length using criteria from the *Green Book*. The designer may have to adjust these rates and lengths to best fit the local conditions.

6. Use the CADD proposed cross section input file to obtain cross sections. Use input files to obtain end areas, catch points, earthwork volumes, accumulated cut and fill volumes and the mass ordinates.

   The CADD uses the average end-area method of determining volumes. The total volume of earthwork is the sum of the volumes of the prismoids formed by adjacent cross sections.

   When using the average end-area method, the prismoid is treated as a prism whose cross section is the mean of the two end areas of the prismoid. Equation 9.4(5) presents the formula for use in the average end-area method.

$$V = L\left(\frac{A_1 + A_2}{2}\right) \qquad \text{Equation 9.4(5)}$$

   Where:

V	=	Volume (m^3 (ft^3))
A1 and A2	=	Cross sectional end areas (m^2 (ft^2)).
L	=	Distance between the cross sections (m (ft)).

   This formula is approximately correct. Due to its simplicity and substantial accuracy in the majority of cases, it has become the formula in common use. It gives results, in general, larger than the true volume.

   If desired, CADD will adjust excavation volumes for curvature. Normally, this is not necessary, but in cases where there is a preponderance of curvature in one direction, consider adjustment.

   Use the added quantities feature to add or subtract miscellaneous excavations for work (e.g., subexcavation, road approaches).

7. Make any adjustments to the line of grade to balance the earthwork quantities. If a line change achieves this, repeat Steps two through four. For a grade change repeat Steps two through seven.

8. Compute the clearing quantities using the Clearing Program. The quantities should include the rounding shown on the standard plans or any other limiting parameters requiring adjustment to clearing distances beyond the slope stakes.

9. Use the Seeding Program to compute the areas of seeding. The quantities for seeding should include the rounding shown on the plans.

9.4.4 Earth Retaining Structures

9.4.4.1 Determination of Need

The first step in the earth retaining system design process is to determine that a retaining structure is needed. The determination may be needed early in the environmental/location stage of the design, or it may come later, at the preliminary design stage. The Project Manager makes this determination in consultation with other involved disciplines and agencies. The Project Manager must consider environmental and historic constraints, as well as physical constraints.

The Project Manager must determine if a retaining wall is the best choice to provide the needed function to meet the constraints established. Retaining wall systems must be considered with other alternates (e.g., fills, cuts, changes in alignment, mechanically stabilized earth (MSE) slopes). The decision process is to site-specific to be completely defined, but the Project Manager should document the project conditions and constraints that were considered in the analysis.

9.4.4.2 Alternative Wall Systems

When it is determined that a retaining wall is needed, FLH must permit all retaining wall system alternatives that are determined to be technically suitable, and aesthetically acceptable to land-owning agencies. The recent changes in technology have rapidly increased the number of retaining wall systems available, which has made determining the most suitable wall alternatives more difficult. This has highlighted the need for consistent design guidance to help Project Managers select and design appropriate wall types to be permitted at each site.

The Project Manager must decide which alternative systems will be designed and included in the contract, and which wall systems will be permitted as alternative contractor designs. Options the Project Manager may consider include:

- FLH may prepare the designs for all competitive alternatives,
- FLH may prepare the designs for the most likely one to three alternatives,
- FLH may list acceptable alternatives while the final selection and designs are prepared by the contractor, and

- FLH may prepare the designs for the most likely alternative and permit additional alternatives that could be designed by the contractor.

Any of these approaches may be appropriate depending on project conditions and constraints. On large projects, the third option should generally be provided. On smaller projects, the fourth option may be necessary. The Project Manager must determine the final number of complete alternative designs included in the contract. The alternatives permitted for design by the contractor normally include all remaining wall systems that the Project Manager determines to be technically suitable, economically competitive and aesthetically acceptable to the land-owning agencies.

The Project Manager must avoid permitting only one retaining wall system, if the system is proprietary. The Project Manager will ensure that contracts specifying a proprietary wall system have at least one other reasonably competitive proprietary or non-proprietary wall system permitted as an alternative. The following applies to retaining wall systems:

9.4.4.3 Design Guidelines

All alternatives permitted by FLH contracts must be designed in accordance with the *Guidelines for the Design of Retaining Wall Systems*. These *Guidelines* are a summary, mainly by reference, of acceptable design criteria and other information for each wall system that may be considered for use in FLH contracts. These *Guidelines* assure consistent FLH designs and encourage competition by permitting as many contractor designed alternatives in the contract as possible. These *Guidelines* are used by the FLH in its designs, by A&E firms in designs done for FLH and by the construction contractor for alternative designs.

In addition to design criteria, the *Guidelines* contain other information, including wall system limitations, materials specifications and construction specifications necessary for a construction contract. The *Guidelines* presents a checklist of all retaining structure geometric and design data (e.g., original and final vertical profiles, beginning and ending stations, foundation capacity, backfill criteria, soils, angle) needed for the design of each alternate wall system. This checklist will help ensure that the Project Manager provides all design data for consultant and contractor designed wall systems in the contract package. The FLH *Guidelines* permit consistent design and review of retaining walls. The *Guidelines* will be updated as new retaining wall systems are added to the list of alternative wall systems that may be considered for use on FLH projects.

Each FLH Division must have a process to ensure that any wall used on FLH projects is designed using the procedures in the design *Guidelines*. The process must include a review of designs of proprietary walls and those prepared by A&E firms to ensure the procedures in the *Guidelines for the Design of Retaining Wall Systems* have been used.

9.4.4.4 Selection of Wall Types

Once it has been determined that a wall is needed, the Project Manager must determine which wall system alternatives are permitted. The Project Manager will coordinate with the land-owning agency and a FLH interdisciplinary team. The team is typically made up of geotechnical, highway and bridge design engineers. The level of involvement of the individual team members will vary depending on the type and function of the wall. The Project Manager must consider spatial, behavioral and economic factors in determining the alternatives to be permitted. These evaluation factors include:

- constructability,
- maintenance,
- schedule,
- aesthetics,
- environment,
- durability or proven experience, and
- cost.

The Project Manager must document the selection process. The documentation may be especially useful when selection and non-selection of proprietary retaining wall systems are challenged. The Project Manager may limit the number of alternative wall systems to be permitted based upon an analysis of the specific constraints and conditions. The analysis must consider the complexity of the wall system to the site.

The Project Manager normally will consider only retaining wall systems included as part of the *Guidelines for the Design of Retaining Wall Systems*, unless the interdisciplinary team proposes an unusual situation, or an experimental wall system. In these situations, the Project Manager must ensure the design guidance and specifications are made available. The wall systems that are normally considered are listed in the *Guidelines for the Design of Retaining Wall Systems*. This list shall be updated as new wall systems are added, as provided in Section 9.4.4.5.

9.4.4.5 Retaining Wall Systems

A description of the retaining wall systems is included in the *Guidelines for the Design of Retaining Wall Systems*. Generally, all of these systems have design guidelines included in the *Guidelines for the Design of Retaining Wall Systems*. However, some systems described in Section 9.4.4.5.2 may not be listed in the *Guidelines*.

9.4.4.5.1 Design Considerations

A retaining wall is a structure built to provide lateral support for a mass of earth or material and a variety of dead and live load surcharges. The layout, design specifics and construction details of a wall consider the following:

- highway geometrics,
- topography and subsurface conditions,
- traffic characteristics,
- length and height of wall required,

- type of material to be retained,
- presence of ground water,
- routine and special loading conditions, and
- visual appearance of the completed structure.

Retaining structures resist applied loads by a variety of methods including structure weight, structural stiffness and load transfer, and internal and external restraining elements.

Walls installed near the edge of a traveled way can serve as traffic barriers if they have an approved traffic barrier design incorporated into the wall details.

The wall selected must be capable of supporting the temporary loads which occur during retaining structure construction. The design surcharges for standard walls must be shown on the *Standard Drawings*.

The design of a retaining structure consists of an analysis of loads that will act on the structure and the development of a structure to withstand these loads safely. In addition, the structure and adjacent soil mass must be stable as a system, and vertical and horizontal deformations anticipated must be within acceptable limits.

A primary cause of retaining wall failure is the additional load imposed by hydrostatic pressure due to saturated soils behind the wall. The design must provide adequate drainage facilities for the site to prevent entrapment of water.

Designs should use native soil for backfill if it meets the requirements for particular wall system.

All retaining walls require an investigation of the underlying soils by the Geotechnical Unit. Chapter Six provides details on conducting and reporting the investigation.

Where conditions warrant, retaining walls shall be designed with an aesthetically pleasing appearance compatible with other structures in the area and the surrounding terrain. Although economics generally dictate wall selection, an aesthetic wall facing treatment could be an overriding selection factor. Consistent architectural treatment and economy of scale will frequently result in the same wall type being used throughout any given project.

Aesthetic requirements may include the wall's material, the top profile, the terminals and the surface finish for texture, color and pattern. Short sections of walls should be avoided if possible.

The Project Manager must give land-owning agencies, cooperators and resource agencies an opportunity to provide guidance and recommendations for wall selections.

When the design includes proprietary wall systems, the designer must contact the company representatives during the design stage to obtain general information on timeframes, detailing, oversight responsibility and other factors necessary to complete the design and construct the wall. The wall companies will require specific site information (e.g., typical cross sections, plan and profiles, soils and foundation criteria, special design parameters).

An experienced structural or geotechnical engineer for the proposed retaining wall must design all retaining walls that are not included in the *Standard Drawings*. Hydraulic engineers must review any wall designs potentially threatened by flood waters or located in a floodplain. Geotechnical engineers must prepare external stability analyses and prepare or review all special foundation designs.

Additional information on retaining wall design may be found in Chapter 10, Section 10.4.12 and Chapter 6, Section 6.4.3.

9.4.4.5.2 Retaining Systems Types

There is a wide variety of retaining wall types available to the designer within each system. Each type has its limitations and usefulness. The following walls are commonly used in highway construction. Families of retaining wall systems have similar characteristics, advantages and disadvantages; yet each wall product within the family generally has some unique design and construction features. The general descriptions and advantages and limitations of each system are discussed.

1. **Gravity Walls**. Gravity walls are usually most cost-effective for smaller wall areas and lower heights since they are relatively expensive because they are materials and labor intensive. They are generally most suitable for fill and widening applications.

2. **Mass Concrete Walls**. The economic overall height of mass concrete walls is about 1.2 m (4 ft). Short sections with heights up to 2 m (6.5 ft) are acceptable. Mass concrete gravity walls can be used in conjunction with cantilever walls if long stretches of design heights less than 1.2 m (4 ft) are necessary.

3. **Reinforced Concrete Cantilever and Counterfort Walls**. Cantilever walls have standard design heights up to 10 m (33 ft) but are most economical below 6 m (20 ft). They lend themselves readily to a variety of aesthetic facial treatments. The following applies:

    a. *Concrete, L-Type Cantilever*. A concrete, L-type cantilever may be suitable where site restrictions do not allow for a footing projection beyond the face of the wall stem. This wall and counterfort walls require special designs. The major disadvantage of these walls is their low tolerance to settlement. Piling can provide adequate foundation support, but greatly increases the overall wall cost.

    b. *Counterfort Walls*. Counterfort walls are economical compared to cantilever walls for wall heights less than 6 m (20 ft) and for long wall lengths. The intricate forming required generally causes higher costs for counterfort walls than for cantilever walls above this height. Counterfort walls may also prove economical over MSE walls where base width considerations require a minimum width.

4. **Buttressed Walls**. A buttressed wall is relatively expensive. It is frequently constructed where right-of-way is unavailable for other wall types. Historically, these walls have

been used in the 9 m to 15 m (30 ft to 50 ft) height range; however, more recently developed systems (e.g., ground anchors, reinforced soil) have reduced their application significantly.

5. **Gabion Walls**. Gabion walls consist of compartmented metallic mesh containers filled with select 100 mm to 150 mm (4 in to 6 in) backfill. They have been successfully constructed to heights of 12 m (40 ft) with adequate foundation support. The walls are somewhat flexible and tolerate some settlement. The walls are aesthetically pleasing because they blend well into areas of rugged terrain. Gabion walls are relatively inexpensive if a source of rock is locally available and labor is inexpensive.

6. **Crib Walls**. Crib walls are somewhat flexible and will tolerate some differential settlement along the axis of the walls. Crib walls not constructed on tangent alignments usually require special detailing, particularly when the wall face is battered. Because open crib wall faces can be climbed, they are not recommended for urban sites where they will be accessible to the public. Project topography and cost of select backfill and labor significantly influence the cost effectiveness of crib walls. Crib walls are constructed without structural foundations and are not suitable where marginal foundation soils exist.

   Concrete crib walls have been constructed up to heights of 15 m (30 ft), but a 6-m (20-ft) height is probably the limit of economic consideration. Concrete crib may be closed face and, therefore, useful where impinging drainage is a problem. Concrete crib walls may also be precast modules of various sizes and shapes. Some walls have planters incorporated in their faces to grow shrubs and vines to conceal the walls.

   Metal crib walls have standard design heights of up to 11 m (36 ft). The wall elements are light in weight, easily transported and installed and, therefore, suited for relatively inaccessible installations and emergency repairs.

   Timber or log crib walls have standard design heights up to 6.7 m (22 ft). This wall system has a rustic aesthetic value that makes it popular for use in certain locations (e.g., parks, National forests, primitive areas). It is also well suited for use on detours or for stage construction. When all of the wood members are pressure preservative treated, the service life of a timber wall is comparable to that of concrete or metal crib walls.

7. **Slurry Walls**. Slurry walls are used when a wall is needed before the surrounding soil is excavated or where ground water is a problem. A trench is excavated for the wall and simultaneously filled with a bentonite or other type of slurry. The slurry restricts the ground water flow and holds the trench sides in place. This is followed by placement of reinforcing steel in the slurry-filled trench and then by placement of concrete by tremie or a concrete pump. After the concrete has cured, the excavation can proceed.

   When one of these walls is exposed to view, some form of facing (i.e., precast, cast-in-place, shotcrete) will provide a more pleasing appearance. In general, slurry walls are designed as cantilever walls without footings. Tiebacks are compatible with this type of wall. Slurry walls are seldom used in transportation applications, other than large urban projects, due to their unique features and extremely high unit costs. Slurry walls are only applicable for retaining walls in cut situations.

8. **Rock Walls**. Rock walls consist of stacked large rock, used primarily in cut sections where very good soil exists. These walls provide erosion protection and limited earth support. They are generally 5 m (16 ft) or less in height for cut sections and less than 3 m (10 ft) in fills.

9. **Modular Precast Concrete Walls**. This wall system consists of precast, interlocking and reinforced concrete elements of varying size depending upon the application. Most of these wall systems are proprietary and are typically available and cost competitive on a regional basis. Each element is rectangular in shape. Once the units are in place and locked together, they are backfilled with free draining material.

   These wall systems have been constructed to heights of 18 m (60 ft), but are seldom competitive above 9 m (30 ft). Unlike metal crib walls, these walls are always used in conjunction with structural footings and require a deep foundation in marginal and poor soils. Wall designs over 12 m (40 ft) in height, walls designed to support bridge abutments on spread footings and walls designed to be installed in locations of excessive foundation settlement must be approved by the geotechnical and structural staff before using.

   Modular precast concrete walls are easy to install and quickly placed. Exposed aggregate finishes or other surface textures can aesthetically enhance the wall face.

10. **Cantilever Pile Walls**. These walls include cantilever, sheet, anchored or soldier pile walls. The walls consist of sheet or soldier piles made from concrete, steel or timber; either driven or placed in drilled holes and backfilled. The walls commonly have concrete facing or timber lagging.

    These walls are suitable where horizontal deformations are not critical, but are costly and become impractical at heights of 5 m (16 ft) or more. The net wall cost is also significantly influenced where the embedded portion of the wall requires significant rock excavation.

    In embankment sections, a cantilever pile wall may be an appropriate solution for roadway widening where design heights are relatively low. They are also practical for correction of slope instabilities depending on design height, loadings and site conditions.

11. **Anchored Walls**. These walls are also referred to as tieback walls. Routine wall designs go up to heights of 15 m (50 ft). The walls are practical in cut sections where a wall is needed before the soil is excavated and are appropriate where cantilever walls are not cost effective. Anchored walls require a specialty contractor and are not suitable in certain soil types. These walls generally require some type of facial treatment for aesthetic purposes. These walls are commonly utilized in conjunction with temporary excavation support based on the need for deformation control and economics.

One advantage of a tieback wall is that it causes minimal disturbance to the soil behind the wall and to any structures resting on this soil. At a wall height of about 5 m (16 ft), the walls may become economical compared with cantilever construction. The number of tieback rows, spacing and loading is project specific. Tiebacks offer the advantage of construction confidence, since each tieback is tested beyond its design load as the basis of acceptance. Geotechnical and structural expertise is essential for all wall designs of this type. Tieback walls can be built in a fill side situation. However, difficulties with construction of the fill over the ties and control of the face deflections must be considered in the design before using this wall type in fill side situations.

12. **Mechanically Stabilized Earth (MSE) Walls**. MSE walls consist of facing elements, metallic or polymeric reinforcing elements, and a cast-in-place or precast facing. Many of the available systems are proprietary. MSE walls offer cost-effective alternatives for fill-type retaining structures in the height range of 5 m to 15 m (16 ft to 50 ft). MSE earth retaining systems work best used in embankment situations and will tolerate considerable magnitude of horizontal and vertical deformations.

    The walls work on moderately poor foundation soils and are flexible enough to accommodate some settlement. Transitions in the foundation material along the base of the wall require special attention. These walls have considerable economic advantage for temporary applications and detours.

    During construction, the proprietary wall company should be required to furnish the wall Materials and/or arrange for their production. Periodic technical assistance is also usually available to the wall installation contractor at the project site.

    Several types of MSE walls use a welded wire mesh, a polymer mesh or fabric. Some examples of these types of MSE walls follow:

    a. *Welded Wire Walls*. Welded wire walls are a patented system marketed by the Hilfiker Retaining Wall Company. These walls use metallic welded wire mat units that serve as both the soil reinforcement and facing element.

    b. *Geotextile and Geogrid Walls*. Geotextile wall systems use geotextile for the soil reinforcement and can use a variety of facing elements depending on project requirements. They are not proprietary and can be designed in-house without infringing upon a patent. The face can remain exposed if the geotextile is treated to prevent decay from ultra-violet rays. Concrete panels, mortarless masonry, tar emulsion or shotcrete coatings make good facing materials. Consider this type of wall for temporary wall installations.

       Geogrid walls use a high tensile strength plastic grid as the soil reinforcing element of the wall. The geogrid can be precast into concrete facing panels, can be used with precast segmental block facing elements as the wall is constructed or attached to precast face panels after wall construction. Some wall facing details permit the construction of battered walls and walls which permit the development of vegetation (a “green wall”). All designs must be approved by the geotechnical and structural staff. Geogrid walls are proprietary wall systems.

c. *MSE Slopes*. The MSE Slopes use geogrid or geotextile for soil reinforcement. They may be used as alternatives for retaining walls in some situations. The MSE Slope is constructed similar to MSE Walls, except the slope does not have a structural facing and is designed using slope stability methods. MSE structures with slopes between 70 degrees and 90 degrees are classified as retaining walls and are designed using retaining wall design procedures. When applicable, MSE slopes will typically be more cost-effective than MSE walls.

d. *Soil Nailing*. This type of wall uses grouted metal bars as soil reinforcement. Soil nailing is a cost-effective wall system suitable for use either as temporary shoring or for new wall construction in cut applications, grade separation, widening and rehabilitation of existing retaining walls. The fundamental concept of soil nailing is to reinforce and strengthen the existing ground by installing closely spaced grouted steel bars called “nails” into a slope or excavation as construction proceeds from the “top down.” Similar to tieback walls, this top down construction technique offers the significant advantages of continuous support of the excavation (and adjacent structures if there are any), cost savings through elimination of the need for structural excavation and imported wall backfill (as for conventional gravity cut walls) and reduced environmental impact.

The typical soil nail wall construction sequence includes a progressive repetition of 1-m to 2-m (3.3-ft to 6.5-ft) high vertical to near vertical excavation lifts, followed by installation of nails and application of a reinforced Geogrid walls shotcrete facing. The reinforced shotcrete facing stabilizes the excavation face between the nails. When required due to local instability of the excavation cut face, the order of nail and shotcrete installation can be reversed. On permanent walls, a cast-in-place concrete facing is usually constructed over the shotcrete facing.

The nails are typically grouted into predrilled holes. The nails are typically referred to as “passive” inclusions. The term “passive” means that the nails are not pre-tensioned, as are tiebacks, when they are installed. The nail bars are forced into tension as the ground deforms laterally in response to the loss of support caused by continued excavation. Therefore, lateral deformation of the ground immediately behind the top of wall is typically greater with a soil nail wall (typically 0.001 H to 0.004 H, where H = wall height), than with a tieback wall. Several alternatives are available where existing structures:

- cannot tolerate these deformations; and
- are located within a lateral distance of up to one-and-a-half times the wall height (H) behind the top of proposed wall.

Either a tieback wall should be used, or one or two rows of tiebacks should be used in the upper part of the nailed wall in addition to the nails to limit deformation.

In cases where either tiebacks or soil nails are appropriate, soil nails are typically more economical. This is due primarily to:

- elimination of soldier piles,
- faster construction, and
- smaller equipment is required with soil nailing.

Soil nail walls cannot be used in all types of ground. For soil nail walls to be most economical, they should be constructed in ground that can stand unsupported on a vertical or steeply sloped cut of 1 m to 2 m (3.3 ft to 6.5 ft), for at least one to two days. Soil nail walls are not suitable in loose cohesionless soils (e.g., caving sands) below the water table.

9.4.4.5.3 Contracting Procedures

The contract frequently will include end result specifications, furnishing only line diagrams, design criteria and an estimate of wall area or other pay item units. The contract may include all construction details for all acceptable alternative retaining wall systems, or it may include one or more complete designs and permit other contractor furnished designs. The Project Manager must make this determination with input from the inter-disciplinary team and the Construction Engineer, considering the project size and the number of retaining walls involved.

Guidance on information needed by bidders is included in FHWA's *Geotechnical Engineering Notebook, Geotechnical Guideline No. 2*. The information needed by bidders includes the following detailed geometric information, subsurface investigation, structural requirements and geotechnical design data:

1. **Geometric**. The following provides the geometric information needed for the contract:

   - beginning and ending wall stations,
   - profile elevation of top of wall and roadway and cross-sections,
   - horizontal alignment,
   - construction details of appurtenances in the area,
   - right-of-way limits,
   - stage construction sequence and traffic control needs,
   - foundations elevations and locations of unsuitable materials, and
   - estimated wall area.

2. **Subsurface**. The subsurface investigation should include:

- shear strength and consolidation properties of foundations materials, and
- shear strength and unit weight of backfill.

3. **Structural and Geotechnical**. The bidders should include the following information for the structural requirements and the geotechnical design data:

- design life (minimum service life) – typically 75 years,
- safety factors for overturning, sliding and stability of temporary slopes,
- allowable foundation bearing pressure and minimum embedment depths,
- maximum tolerable differential settlement,
- MSE internal design requirements,
- external loads,
- drainage requirements,
- backfill requirements, and
- facing requirements.

In addition, the *Notebook* provides guidance on information and requirements which should be included in supplier prepared designs and plans.

The bid advertisement period must be extended from 30 to 45 days, or longer, if the Project Manager determines projects with alternative bids and Contractor designed walls require additional bid preparation time.

One advantage of the development of the FLH *Guidelines for the Design of Retaining Wall Systems* is the reduction or elimination of the need to review and analyze complex proprietary wall systems under tight contractual time constraints. The Project Manager should ensure that Special Contract Requirements are included in projects that prohibit submission of value engineering change proposals (VECPs), which propose to change the basic wall system alternatives permitted. This restriction is possible since the use of the *Guidelines* ensures that all suitable wall systems have been considered and are included in the contract. However, VECPs may be permitted on the components of the wall systems (e.g., facing, connection details).

The contract specifications must identify the procedures fro the FLH review of designs and working drawings submitted by the contractor, similar to the bridge process for reviewing and approving falsework drawings. The information that is required from the contractor for review of wall submittals must be specified in the contract, along with the amount of time required for FLH reviews. The contract must include provisions for additional time needed to permit the working drawings to be reviewed by the A&E firm that did the original design, if appropriate. The specifications must define when the time count begins for both the review of initial submissions, and for subsequent reviews when changes are required. The contract shall specify the number of sets of drawings needed by FLH.

The pay unit for contractor designed alternative walls must be identified. The impacts of alternative wall types on the units of measurement should be considered if a common measurement (e.g., wall face area) is used. If alternative wall systems require different pay item measurements, alternative bid items must be required. The contract must include a method for adjustment of quantities for field changes if a lump-sum payment is used.

4. **Specifications**. All wall systems permitted as alternatives must have construction and materials specifications available to the designers. Construction and materials specifications are referenced or included in the *Guidelines for the Design of Retaining Wall Systems* for all wall systems that may be considered for use on FLH projects. The applicable portions of these specifications must be included as part of contracts for all wall systems that do not have specifications covered in the latest FP.

5. **Review Procedures**. The construction operations engineer is responsible for initiating the review of contractor-designed retaining wall systems and working drawings. The working drawings will normally be reviewed by the geotechnical engineer for MSE systems, and by the structural engineer for tie-back and cantilever systems. The geotechnical engineer will be the lead for all wall system reviews. The geotechnical engineer will ensure the approval is made within the time limits specified in the contract, and will keep the construction operations engineer informed of the status of the review. Any communications that must pass directly between these reviewers and the contractor must be documented and provided to the construction operations engineer.

6. **Consideration of New Retaining Wall Systems**. The FLHO will keep a current list of retaining wall systems that may be considered for use on FLH projects. This list is for general guidance of designers in determining retaining wall systems that may be considered for use on FLH projects, and is not a blanket endorsement of the retaining wall system.

   The retaining wall system review process will identify the general design concepts used, and will determine if these concepts are acceptable for use on FLH projects or if they must be modified to be acceptable. Also, the wall system review will determine the availability, durability and constructability of new systems. In addition to possible modifications to the supplier's design process, the review will generate any materials and construction specifications needed for inclusion in the *Guidelines for Design of Retaining Wall Systems*. Finally, the review process will determine any limitations in the use of the system (e.g., maximum wall heights, special materials, construction requirements).

   FLHO will not directly solicit data from suppliers and manufactures to determine if newly developed wall systems are acceptable. Periodically, the FLHO will solicit information from selected partner agencies (i.e., State, Federal, professional engineering organizations) concerning their evaluation and approval of wall systems. The FLHO will review the partner agencies design approval process and will adopt those wall types which meet *Guidelines for Design of Retaining Wall Systems* and other criteria specified below. FLHO, working with the divisions, will update the list as new walls are determined to be acceptable for use on FLH projects.

Information required from partner agencies includes:

- size and capacity of the supplier;
- geographical availability of the system;
- theoretical basis for the design, including when and how the theory was developed;
- practical basis for the evaluation of the design by FLH engineers, including an design manuals, charts or software needed for the design;
- laboratory and field experiments that support the theory;
- practical applications with descriptions and photos;
- limitations and disadvantages of the system;
- list of owner agencies using the system, including contact names, addresses and phone numbers. The list must include documentation that the system has a successful “track record” of several installations. The actual number of successful installations required will depend on the FLH reviewers’ concerns, but normally it is between two and ten installations;
- details of wall elements, analysis of structural elements, design calculations, factors of safety, estimated life, corrosion design procedure for soil reinforcing elements, procedure for field and laboratory evaluation including instrumentation and special requirements, if any;
- sample material and construction control specifications showing materials type, quality, certifications, field testing, acceptance and rejection criteria and placement procedures;
- a well-documented field construction manual describing in detail, with illustrations where necessary, the step-by-step construction sequence;
- typical unit costs supported by data from several actual projects;
- a certification of the product and procedure by an independent professional engineer; and
- types of architectural facing treatments available or possible.

Normally, the Division geotechnical engineers are responsible for coordinating the review. The principle reviewer determines if the system warrants further review. The reviewer ensures that all information needed from the above list has been provided.

The principle reviewer determines if additional reviews by geotechnical engineers, bridge engineers and other technical experts within FLH, FHWA or outside consultant firms are needed.

Much of the information requested from the suppliers is needed to determine the acceptance of the design procedure. However, some of the data permits the reviewers to develop additional information for designers and project managers. Examples of this type of information for designers and project managers are as follows:

- constructability;
- versatility/suitability for varying site conditions;
- suitability for architectural facing; and
- limitations on usage (e.g., maximum fill heights).

The principle reviewer will send copies of the review package that they determine to be acceptable to FLHO and the other FLH divisions for concurrence. All retaining wall systems considered for use on FLH projects must be included in the *Guidelines for Design of Retaining Wall System.* A new retaining wall system will not be added to the list until all design guidelines, wall system limitations and materials and construction specifications have been developed and approved for inclusion.

9.4.5 Drainage Design

Drainage facilities convey both normal surface and subsurface waters (and within reasonable limits, expected flood and storm waters) across, along or away from a highway. The designer considers the most cost-efficient and practical manner to do this without undue damage to the highway, the drainage facility or adjacent stream channels and property. Various types of drainage methods will accomplish this, including the use of open channels, riprap and channel lining, bridges, culverts, storm drains, underdrains and related appurtenances. Some installations require provisions for fish passage.

Chapter Seven provides information, references and methods for designing drainage facilities. See the *Roadside Design Guide* for information on roadside safety in the design of drainage structures.

The designer must include all of the drainage facilities in the contract plans and ensure that the *Specifications* contain provisions for these facilities.

The designer is responsible for the design of drainage facilities and for submitting requests and data to the hydraulics engineer, the Bridge Unit and the Geotechnical Unit. The designer normally designs all minor drainage structures and appurtenances (e.g., small culverts

(1200 mm (48 in) and smaller), end sections, catch basins, inlets) as well as minor drainage channels and ditches.

Large culverts and channels are usually sized by the hydraulic engineer or by the designer with the assistance of the hydraulic engineer.

Bridge design (e.g., layout, minimum opening under bridge, pier placement) is the co-responsibility of the bridge unit and the hydraulics engineer.

The Geotechnical Unit is responsible for specialized design of underdrains, horizontal drains, drainage blankets and subdrainage systems using geotextile fabrics. They are also responsible for obtaining pH values of soils and waters and for determining foundation materials for bridges and large culvert installations.

See Chapter 7, Section 7.1 to determine the responsibilities of drainage design.

The designer furnishes lines, grades, cross sections, detail maps and vicinity maps to the hydraulics engineer and the Bridge and Geotechnical Unit for design.

The designer often adjusts grades (and lines) to provide adequate cover for culverts, minimum clearance under bridges or for other constraints imposed by drainage facility designs performed by others.

Early in the design process, the designer should consult with the hydraulics engineer, the Bridge Unit and the Geotechnical Unit where any special needs are foreseen. Also, early in the design process, the designer should discuss the need for various Federal, State and local permits, and approvals with the hydraulics engineer.

The designer must review the environmental documents and correspondence with fish and wildlife agencies and review all permits to ensure that all drainage requirements are in the contract.

The hydraulics engineer or the Bridge Unit designs the larger and more complicated drainage facilities. However, the designer must have familiarity with the design principles and methods to supply adequate information so others can design these facilities. The designer should know the minimum vertical dimensions of structures to adjust the highway grade, and should be aware of alternative designs that could affect the line and grade of highway.

To design any drainage facility, the quantity of flow that the facility must pass has to be determined. Various methods as explained in Chapter 7, Section 7.3.1 will accomplish this. This quantity of flow or discharge is designated by the letter “Q” in hydraulic equations and charts. The discharge is the number of cubic meters per second (cubic feet per second) of water flowing into or out of a drainage facility or a segment of the facility.

9.4.5.1 Channels and Ditches

Drainage channels, other than normal roadway cut ditches and channel changes of streams generally require a design by the hydraulics engineer when the discharge is significant. The designer shall furnish approximate lines and grades, existing site conditions and cross sections for the channel design. Include provisions for fish habitat and aesthetics in the design. Good fish habitat includes pools, riffles, boulders, logs and gravels in the streambed and brush and shade on the stream banks. In order to design channel changes properly, the hydraulics engineer needs to know which features to include. The designer shall include typical sections and detailed drawings of drainage channels and channel changes in the plans. See Chapter 7, Section 7.3.2 for more information on open channels.

Roadway cut ditches must meet AASHTO, State or county minimums for depth requirements and foreslopes. The minimum depth should be 150 mm (6 in) below the subgrade shoulder. Cut ditches serve two primary purposes:

- to keep the ground water level below the subgrade, and
- to drain surface runoff and small streams into culverts and cross drains.

The amount of water that the ditch can carry and the depth of flow vary with the grade of the ditch line. On very flat grades, the water may not drain fast enough to prevent saturation of the subgrade. This situation may cause pavement failures. The designer can alleviate this problem by using deeper or flat bottom ditches, steepening the ditch grade, decreasing the distance between cross drains, paving the ditch or using slotted drains. Give first consideration to the ditch grade. Use a minimum ditch grade of one-half percent. Consider special design for grade lines of ditches on long crest and sag vertical curves and in superelevation transition areas where ditch grades may be flat for substantial lengths.

In soils subject to erosion, consider lining the ditches with rock or some other suitable material especially on grades steeper that three percent. Consult the hydraulics engineer when ditch erosion is a possibility. (See Chapter 7, Section 7.3.2.6.)

9.4.5.2 Culverts

For design purposes, there are two categories of culverts:

1. **Category One**. Category One culverts are minimum sized culverts used for cross drains to carry off intermittent roadside ditch water or water from very small drainage areas. They normally range in size from 300 mm to 600 mm (1 ft to 2 ft) in diameter. The design of these culverts consists of locating them on the cross sections, determining the end treatment (beveled ends, end sections, catch basin), establishing grades, cover, structural excavation and showing the locations on the plans.

2. **Category Two**. Category Two culverts are sized to carry perennial streams and large runoffs. They require hydraulic design procedures to determine size. The sizing of these culverts is either done by or checked by the hydraulics engineer.

The designer locates the culverts on the detail map and procedures plotted cross sections to determine the length of culvert invert, inlet and outlet elevations and available depth for headwater. After sizing the culverts, determine the maximum cover of fill over the culverts and calculate the structural excavation.

To locate culverts for a project, obtain a plot of the ditch profile and study the cross sections and the detail map. Streams crossing the alignment, draws and low spots in fills and ditch lines are the obvious sites for culverts. In long cut sections between the obvious culvert sites, space the cross drains so water does not build up in the ditch line and infiltrate the subgrade or cause erosion problems. There is no set rule for minimum spacing between cross drains because of various types of soil encountered and the wide differences in rainfall in different geographical areas. Consult with the hydraulics engineer on a project-by-project basis for minimum spacing of culverts.

After locating the culverts on plotted cross sections and determining the maximum cover, prepare a drainage summary sheet for the plans. The maximum cover of each culvert determines the culvert wall thickness for alternative metal culvert pipe materials and corrugations or the reinforcement class for conference alternatives. Select the wall thicknesses and reinforcement classes from the *Standard Drawings*. Any required or optional special coatings on metal pipe must be shown in the contract. See Chapter 7, Section 7.3.3 for more information on culverts.

9.4.5.3 Downdrains and Pipe Anchors

Downdrains work well in high fills. Their use may prevent the excessive excavation required to install a new culvert at the bottom of an existing fill. Also consider downdrains where the outfall of a culvert will be on erodible soils. Pipe anchors should be specified for all above ground downdrain installations. Buried downdrains may require an anchoring system depending upon specific sit conditions. For tongue and groove concrete pipe, use concrete anchor blocks on grades steeper than ten percent. For bell and spigot concrete pipe and metal pipe culverts on grades steeper than 30 percent, use pipe anchors as detailed on the approved *Standard Drawing*.

List specific pipe anchors for a project on the drainage summary.

9.4.5.4 Catch Basins and Inlets

Catch basins and inlets are generally associated with curb and gutter sections, storm drains, depressed medians and ends of bridges. They may also be used as a safety measure in roadway ditch lines. In this case, maintain the normal ditch depth at a culvert inlet and provide a traversable grate at the top of the catch basin or inlet.

In curb and gutter sections, space the catch basins and inlets close enough together so water will not spread on the traveled way and create a traffic hazard. Spacing will depend on the gutter grade and cross slope of the road or gutter. Consult with the hydraulics engineer on spacing requirements.

At the lower ends of bridges, design catch basins or inlets to prevent runoff from the bridge gutters eroding the fill slopes at the corners of a bridge.

At culvert inlets, determine the need for catch basins on an individual basis. However, they serve no purpose if slides and siltation will plug them.

For additional guidelines on roadway drainage, see Chapter 7, Section 7.3.4.

9.4.5.5 Storm Drains/Storm Sewers

Storm drain systems and urban drainage systems require design by or in consultation with the hydraulics engineer. The designer must furnish layouts, lines and grades and culture and land features for each drainage area. The designer must include detailed drawings of the system in the plans.

For further information, see Chapter 7, Section 7.3.5.

9.4.5.6 Underdrains and Horizontal Drains

The Geotechnical Unit should design underdrain systems and horizontal drains based on field observations and exploration of subsurface conditions. The designer will have to incorporate them in the plans and provide detailed drawings for their construction.

9.4.5.7 Riprap

The hydraulics engineer determines the class, thickness and cross section of riprap for slope protection along streams and lakes, and for ditch and channel lining. The roadway designer incorporates the data in the plans. The class, thickness and typical section must be shown in the plans and specifications. See Chapter 7, Section 7.3.2.6 for more information on channel stabilization.

Place riprap around culvert inlets and outlets to prevent erosion and undercutting.

9.4.5.8 Energy Dissipators and Outlet Basins

In areas of erodible soils, consider energy dissipators at the outlet of downdrains and culverts with high outlet velocities and in channels at points where the grade flattens. Energy dissipators may be in the form of riprap outlet basins, stilling wells, weirs or concrete structures. For more information, see Chapter 7, Section 7.3.3.9.

9.4.5.9 Erosion Control

Determine the need for various items of erosion control and include the items in the contract. The type and extent or erosion control measures will depend mostly on the soils and streams on a project. See Chapter 7, Section 7.3.8 for additional guidelines.

9.4.6 Other Design Elements

Many components go into the preparation of a completed design for a proposed highway facility. This section will establish basic guidelines and direction for the many elements not already covered but that are essential to complete the design package. These elements include culverts, catch basins, curbs, gutters, sidewalks, special ditches and channels, slope protection, erosion control, cattleguards, fencing, etc.

9.4.6.1 Highway Lighting

The purpose of highway lighting is to provide illumination for an orderly flow of traffic and to improve road safety during the hours of darkness. Properly designed and maintained fixed roadway lighting allows the motorist and pedestrian to quickly, accurately and comfortably recognize all significant details in the traffic occupied space.

This section provides warrants, standards and other information on highway lighting installations. An engineer experienced in lighting design should review all highway lighting designs. Generally, the maintaining agency should be contacted to ensure compatibility in lighting hardware and components.

9.4.6.1.1 Warrants

Lighting warrants relate to the need for roadway lighting and the benefits derived. Several factors (e.g., traffic volume, speed, nighttime road use, night crash rate, road geometrics, general night visibility) are important when considering highway lighting. Economic returns for lighting are measurable by the reduction in personal injuries, fatalities, property damage and other societal costs. More effective usage of the road and the possible increase in its capacity also affect the warrants.

Roadway lighting is warranted for the following:

- Urban expressways and arterials, urban collectors having ADT (20) exceeding 5000 and urban intersections have a combined ADT (20) exceeding 10 000.
- Rural interchanges and intersections where the average number of nighttime crashes (N) per year exceeds the number of daytime crashes (D) per year divided by three. (Illuminate when N is greater the D/3).

- Major rest areas located near urban areas or located near available power sources.
- Tunnels where driver's visibility requirements (or needs) during daylight hours require illumination and where the approach roads to tunnels are lighted.
- Pedestrian underpasses and highway underpasses used by pedestrians.
- Underpasses on lighted highways.
- Overhead signs along urban expressways and arterials; and overhead signs at interchanges on roads approaching urban areas.

9.4.6.1.2 Design Values

FHWA's *Roadway Lighting Handbook* gives the levels of average maintained horizontal illuminance and uniformity of illuminance, as well as levels of average maintained luminance and uniformities of luminance for various classes of roadways. The following applies:

1. **Urban Intersections**. Illuminate intersections of arterials and collector roads with other roads in urban areas to a level equal to the sum of the illuminance levels of the intersecting roadways. If only one of the intersecting roads has lights, the intersection requires lighting to a level at least 40 percent higher than the lighted roadway.
2. **Rural Intersections**. Where warranted, illuminate rural intersections to provide visibility of other traffic and physical features that are potential collision objects. Place a minimum of two luminaries and preferably four, per intersection. Maintained average illuminance of the roadway between luminaries shall be ten to 12 lux with a maintained minimum between luminaries not less than three lux.
3. **Overhead Signs**. The level of lighting required for easy recognition and good legibility of overhead signs depends on the ambient luminance behind the sign. There is no approved method for determining ambient luminance.

The following explanations of low, medium and high ambient luminance apply in selecting the recommended design range of average maintained illuminance levels for signs.

1. **Low Ambient Luminance**. Rural areas with no lighting or with very low levels of lighting. This would include background of mountains, deserts, fields, trees and rural roads.
2. **Medium Ambient Luminance**. Urban areas with small commercial developments, lighted roadways and lighted intersections.
3. **High Ambient Luminance**. Areas with high street lighting levels and brightly lighted advertising signs. An expressway through or adjacent to a highly developed downtown area could experience high ambient luminance.

When warranted, illuminate overhead signs to the following levels of average maintained illuminance:

Ambient Background Luminance	Sigh Illuminance (lux)
Low	100 – 200
Medium	200 – 400
High	400 – 800

Maintain a minimum to maximum uniformity ratio of 1V:6H over the entire sign surface.

While the recommended values will provide good sign recognition and legibility for painted or enameled sign surfaces, the highly retroreflective sign materials require special care. In this case, use luminaries especially designed for these materials and strictly follow manufacturer's installation recommendations. In addition, a field test of this type of equipment before accepting it for construction is desirable.

4. **Rest Areas/Parking Lots**. Rest area lighting installations shall not adversely affect the vision (by glare or spill light from the rest area) of traveling motorists along the main roadway. Motorists on the highway passing the adjacent rest area should be able to discern any vehicle leaving the rest area as well as the traffic traveling along the main roadway.

   Recommended average maintained horizontal illuminance levels and uniformities of illuminance are as follows:

Entrance and Exit Gores and Interior Roadways	6-10 lux	G_1 = 1V:3H
Parking and Activity Areas	12-16 lux	G_1 = 1V:3H

5. **Tunnels**. Daytime tunnel lighting assists the driver's eyes to adjust from high levels of luminance outside the tunnel to a low level of luminance inside the tunnel. Drivers' eyes adapted to high outside ambient luminances will not see obstacles just inside the tunnel unless the tunnel is very short and straight. When approaching a very short and straight tunnel, vehicles and other objects show in silhouette against the light of the exit portals. Such tunnels normally need no daytime lighting.

   Tunnels are classified as short or long. A short tunnel has a portal to portal length equal to or less than the minimum stopping sight distance for vehicle operating speeds within the tunnel. A long tunnel has a portal to portal length greater than the minimum stopping sight distance.

A tunnel zone is a length of tunnel roadway equal to the minimum stopping sight distance. A short tunnel will have one tunnel zone and a long tunnel will have two or more. The first tunnel zone in from the entrance portal defines the entrance zone.

The visibility within this entrance zone must be adequate so motorists can recognize vehicles and objects on the tunnel roadway while the driver is still outside the portal entrance. Adequate visibility occurs when the luminance level is at least seven to ten percent of the ambient luminance outside the entrance portal. This ratio applies only to the luminance or brightness level the motorists observe in the entrance zone. The ambient brightness outside the portal will depend upon the sun's path and the surrounding entrance environment.

Although the sun may produce illuminance levels exceeding 100,000 lux on the earth's surface on a clear day, the entrance zone is not automatically illuminated to 10,000 lux to meet the ten percent criterion. Evaluate the actual approach roadway and entrance portal and determine the correct ambient brightness and the anticipated tunnel approach conditions.

The driver's field of view of the adapted brightness must be evaluated at a location along the approach roadway equal to the minimum stopping sight distance in advance of the entrance portal. Design the entrance zone lighting levels for the highest ambient brightness expected at the location.

For a short tunnel, continue the entrance zone lighting level throughout its entire length. However, lighting beyond the minimum stopping sight distance in long tunnels must be progressively reduced to an established minimum level. Beginning at the end of the entrance zone lighting, reduce the levels by steps to not less than seven to ten percent of the previous higher level. Minimum daytime levels in long tunnels should not be less than 50 horizontal average maintained lux on the roadways. Each stepped zone should have a length at least equal to the minimum stopping sight distance.

Since visual adaptation from low to high luminance levels presents no problem, special exit portal lighting is not required unless there is traffic reversal or two-way traffic in one tube of a two-tube tunnel. Such cases justify the installation of symmetrical lighting systems at both ends of the tunnel.

Nighttime illuminance levels and uniformities of tunnels must be about equal to those on adjacent roadways. If, because of mounting height and spacing restrictions, these recommended uniformities are not achievable, exceed the recommended illumination levels somewhat to meet the uniformity requirements. These increased illumination levels, however, should not exceed twice those recommended for the adjacent roadways.

6. **Underpasses**. An underpass is defined as a portion of a roadway extending through and beneath some natural or manmade structure, and having a length to height ratio not exceeding 10:1. Because of its limited length to height ratio, it will not, under normal conditions, require supplementary daytime illumination.

Nighttime illumination levels and uniformities applying to tunnels also apply to underpasses. If warranted, underpasses located on unlighted roadways are lighted to the minimum levels recommended for the roadway types adjacent to these underpasses.

7. **Bridges**. When bridges are a part of a lighted highway or roadway, illuminate them to at least the same levels and uniformities as the adjacent highways or roadways. Under normal conditions, do not light individual bridges on unlighted roads. When lighting is required, use overhead luminaries. Luminaries located at ground level or in the railing (parapet lighting) make it difficult to achieve and maintain the required lighting levels and uniformities.

   Poles, luminaries and lamps mounted on bridge structures are subject to more severe vibration than those located on conventional roadways. Take precautions to minimize luminaire and lamp damage of such installations. This requires special resilient pads inserted between pole base and foundation, a spring loaded lamp holder located opposite the lamp socket to provide two-point lamp support, etc.

   Luminaries must be shielded to minimize glare emitted toward motorists using roads located near and below the illuminated bridge. Shielding may be especially desirable on bridges crossing navigated waterways. For complex and/or multilevel bridge structures, consider high mast lighting.

9.4.6.1.3 Lamps and Luminaries

Lamps and luminaries must be standardized to provide the most economical roadway lighting. Standardization also reduces inventories and simplifies design and procurement of materials for maintenance and repair work. Coordinate with the maintaining agency to verify lamp type selection. The following applies:

1. **Lamps**. Generally all highway lighting, including the lighting of overhead signs, must use high-pressure sodium lamps. There are situations, however, that make the spectral energy distribution (i.e., color) of this light source unacceptable. For these exceptions, use metal halide lamps.

   All lamps must be first-line, high-quality products. The outer envelopes must be heat-resistant glass. The structural design of the arc-tube support must be suitable to withstand the mechanical vibrations expected during a lamp’s normal life cycle without moving or damaging the arc-tube.

2. **Luminaries**. A luminaire is a complete lighting device, less lamp, consisting of a housing, support clamps or a fitter for attachment to the support structure, reflector, refractor or lens (as specified), lamp socket, terminal block, lightning arrester (when specified), an integral or external ballast (as specified) and an integral photo control receptacle (as specified). The luminaire must be capable of operating the specified lamp at the line voltage specified in a completely sealed optical system. The seal of the optical system must be of a design and material to minimize entry of dirt, dust, sand and

other contaminants into the optical cavity. The luminaire, including all its electrical components, must be capable of operating satisfactorily at ambient temperatures covering the range from -5 degrees C to +55 degrees C.

To keep glare to an absolute minimum, use luminaries meeting the cutoff type vertical flux distribution (per ANSI/IES RP-8, 1983). “Semicutoff” type luminaries may, under certain conditions, be allowable. Do not use “Noncutoff” type luminaries.

9.4.6.1.4 Pole Location

The primary consideration in locating light poles is safety. The designer must minimize the hazards of these poles by reducing their number, increasing the offset distance, locating them behind barriers, installing frangible or slip base supports and installing poles in areas with low incidence of vehicles leaving the road.

Use higher lumen output lamps at greater mounting heights to reduce the number of poles. Use high mast lighting on very wide multilane facilities and at interchanges.

If at all possible, install the lighting system in the median. This results in a reduced number of poles, only one run of electrical conductors and usually better use of the light emitted by the luminaries compared to a lighting system installed on both outside edges of the roadway. If the median is wide, use a breakaway or yielding pole located in the center of the median. A wide median width is greater than twice the pole offset (i.e., distance between outside edge of pavement and property line) of an installation along the outside edge of the road. Since most medians on urban freeways are narrow and provided with a barrier, it is often possible to locate the poles on or within these barriers, provided that the following is true:

- The barrier is rigid and considered unmountable by passenger vehicles.
- The barrier is semirigid with enough clearance between barrier and pole to permit deflection.
- The barrier is semirigid but stiffened in the vicinity of the pole to increase beam action and reduce vehicle pocketing.
- Sufficient space is available for safe and proper maintenance of the lighting equipment.

Existing utility poles may be used for attaching luminaire’s mast arms. If the highway is in a depressed section having retaining walls, the mast arms may also be attached to these walls.

Increasing the pole offset distance from the traveled way reduces the hazards of light poles. It is desirable to have luminaries positioned over the outside traveled lane and, as a minimum, positioned over the shoulder.

The offset will depend upon the lengths of standard mast arms. Do not use nonstandard mast arms. Locate light poles without breakaway bases and high masts outside the clear zone. If high mast poles are designed within this zone, install crash barriers (impact attenuators) around them.

Conventional poles located within the clear zone must have frangible or slip bases unless falling poles would create greater hazards.

The hazard of light poles can be further reduced by placing them outside or ramp gore areas and on the inside instead of the outside of curves.

Require frangible or slip base poles in the clear zone and in medians (12 m (40 ft) or wider) or along the outside of the traveled way.

Frangible bases are not appropriate on poles located along sidewalks or other locations where they could fall into heavily traveled roads, on pedestrians, or where a falling pole would create a greater hazard. This is especially applicable to those poles located on narrow sidewalks separating frontage roads form the main roadway.

Select pole locations so the luminaire’s brightness will not produce excessive glare in the driver’s view of cause reflected glare on adjacent overhead signs.

9.4.6.2 Fencing

Fence is usually installed to protect a highway facility from unsafe encroachment by pedestrians, livestock, etc. Generally, fencing replaces existing fence and is usually constructed on the right-of-way line through private lands. Some States have laws requiring fence for all State right-of-way. The designer needs to check the applicable regulations during the design process. The type of fencing and its location shall agree with the right-of-way documents or be agreed to during the plan-in-hand or other reviews of the project.

When the right-of-way line has many abrupt irregularities over short distances, fencing runs should have continuous alignment. This means some right-of-way corners or monuments will remain outside the fence line. Fencing on a continuous alignment has a cleaner appearance and is more economical to construct. In rural areas, the designer should contact the property owners to determine locations for the fence line. In many instances, the landowner will request a fence outside the right-of-way line for ease of maintenance. Attempt to hold the number of fence types to a minimum on any particular project for convenience of construction.

Chain-link fence may be warranted for the following situations:

- through industrial areas,
- at residential developments,
- through military reservations,
- at schools and colleges,

- at recreational and athletic areas, and
- at other locations where maximum protection to prevent encroachment on the right-of-way is necessary.

Generally, a 1800-mm (6-ft) high chain link fence provides protection from encroachments. Sometimes a 1200 mm (4 ft) height is adequate if conditions are noncritical.

Wire fencing warrants apply in all rural areas and in some suburban and urban cases. The fencing may consist of barbed wire, hog wire and other types of metal fabric.

The height of fence can be variable depending on the primary purpose of the fence (e.g., controlling cattle, sheep, wild animals). Some wire fencing can be 3 m (10 ft) high when used to control elk and deer. In some western States, the clear distance from the ground to the first wire is important for antelope crossings.

Metal right-of-way fencing can interfere with airport traffic control radar. When fencing in the vicinity of an airport, review the FAA permit to determine if the fencing will create radar interference. An alternate type of fencing may be appropriate in this case.

Some projects require lograil, jackrail and other types of wood fences on projects for aesthetic and the degree and type of fencing depends on the requirements of each site.

Fence measurement is taken along the slope of the fence. The design quantities should reflect this measurement.

Provide gates, where required, at the locations stated in the right-of-way agreements or as agreed to during the plan-in-hand review of the project. The type and size of gates must be shown on the plans.

9.4.6.3 Cattleguards

Cattleguard substructures must be concrete, timber or steel. The width and type must agree with the right-of-way document or be agreed to during the plan-in-hand review of the project.

Cattleguard wing guards are not considered crashworthy and should be placed outside the clear zone, or treated as an exception to the roadside design. At a minimum, cattleguard widths should be shoulder-to-shoulder or traveled way widths plus 2.4 m (8 ft), whichever is greater.

9.4.6.4 Pedestrian Facilities

Pedestrian facilities consist of sidewalks, hiking or walking trails and pedestrian separation structures. Sidewalks are generally located immediately adjacent to the highway or parking area. Walking and hiking trails are independently aligned and usually serve recreational activities (e.g., paths from parking areas to scenic overlooks). Refer to the *Green Book* in

Chapter 2, *The Pedestrian* and Chapter 4, *Pedestrian Facilities* for pedestrian considerations, as well as the *Guide for the Planning, Design and Operation of Pedestrian Facilities* (AASHTO, 2004). Pedestrian separation structures are not discussed here. The *Green Book* in Chapter 4, *Pedestrian Facilities-Grade-Separated Pedestrian Crossings,* addresses pedestrian structures.

9.4.6.4.1 Sidewalks

Sidewalks must have all-weather surfaces. Provide sidewalks along both sides of urban area highways where there is a need for pedestrian access to schools, parks, commercial areas and transit stops. In suburban residential areas, provide a sidewalk on at least one side of the highway and locate it close to the right-of-way line, if possible.

In lightly populated suburban areas and in rural areas, consider sidewalks only at points of community development (e.g., schools, businesses, industrial plants, transit stops).

In urban and in major residential areas, sidewalks are usually raised. In many suburban and most rural areas, pedestrians use the roadway shoulder. Sidewalks in residential areas have a minimum width of 1.2 m (4 ft). To provide a planting strip between the sidewalk and curb allow a minimum of 0.6 m (2 ft). When constructing a sidewalk adjacent to the curb, widen the sidewalk 0.6 m (2 ft) to accommodate open doors of parked vehicles.

Sidewalks in areas of high pedestrian traffic (e.g., schools, businesses, industrial areas, transit stops) should be wider than the minimum and paved to the curb in most cases.

Raised sidewalks should slope toward the roadway at two percent.

In most cases where pedestrians use the roadway shoulder for walkways, there are no markings or signs for pedestrian use. In areas of known heavy pedestrian use, an additional 1.2 m (4 ft) of shoulder width may satisfy the purposes of a sidewalk. An 200 mm (8 in) solid white stripe should mark the edge of the traveled way at these locations.

Pedestrian crosswalks are regularly marked in urban areas. In residential and rural areas, marked crosswalks are normally not necessary. In the vicinity of schools, convalescent centers, local parks or community centers, marked crosswalks may alert vehicle operators of an unusual situation. For additional details see the *MUTCD* and *Traffic Control Handbook*.

All sidewalk designs must accommodate persons with disabilities. Refer to the *ADA Accessibility Guidelines for Buildings and Facilities (ADAAG)* for design guidelines.

9.4.6.4.2 Walking and Hiking Trails

These pedestrian facilities usually provide connections with existing trails, lead to roadside points of interest, allow access to streams or permit leisurely walks. They often have a natural surface, except in high-use locations. These locations may require paving to protect existing environmental conditions.

The following guides for walking and hiking trails apply when persons with disabilities do not require accommodations.

- The clear area around walking and hiking trails should be 2.4 m (8 ft) laterally and 3 m (10 ft) vertically. Any trees or brush removed from this area must be flush cut at ground level and intruding branches trimmed flush with the tree trunk.
- Walking trails should be a minimum of 1.2 m (4 ft) wide and have a maximum grade of 10 percent. The trail should have independent horizontal and vertical alignment. Always locate a trail outside the clear recovery zone or behind guardrail when it parallels the main roadway.
- Hiking trails should have a minimum surface width of 0.6 m (2 ft) and a maximum sustained grade of 10 percent. The grade may be up to 20 percent for short distances. A hiking trail constructed in a riprap slope, talus slide or other rock slope should have all voids filled at least 600 mm (2 ft) below the rock surface. Provide a 75 mm (3 in) cover of soil or small rock for a final surface.

9.4.6.4.3 Bicycle Trails

Consider bikeways in the overall design of a highway when bicycles would interfere with or jeopardize the safety characteristics of the highways. See 23 CFR 652. The AASHTO publication *Guide for Development of Bicycle Facilities* provides the criteria for the design of bikeways.

9.4.6.4.4 Parking Areas

On FLH projects, parking areas are most often constructed for the scenic, recreational and cultural enhancement of the highway facility. Parking area design is coordinated with the client agency to determine geometrics, capacity, design vehicle type and other related requirements. Special design considerations are necessary to accommodate recreational vehicles at intersections within the parking area to provide safe traffic movement. Parking areas are designed to accommodate persons with disabilities.

The basic design for parking areas can be found on pages 54 and 55 in the FHWA publication *Safety Rest Area Planning, Location and Design*.

9.4.6.4.5 Accommodation of the Disabled

The *Americans with Disabilities Act (ADA) Accessibility Guidelines for Buildings and Facilities (ADAAG)* contains most of the applicable standards. The *Green Book* contains information on sidewalk curb ramps in Chapter 4, *Pedestrian Facilities-Sidewalk Curb Ramps*.

The following accessibility requirements apply to the design of parking areas and loading zones:

- Parking spaces for disabled persons and accessible passenger loading zones must be the spaces or zones located closest to the nearest accessible entrance on an accessible route.

- Parking spaces for disabled persons must be at least 2440 mm (84 in) wide for passenger cars and 3350 mm (132 in) wide for van accessible spaces, and shall have an adjacent access aisle at least 1525 mm (60 in) wide. One in every eight accessible spaces, but not less than one, must be designated “van accessible.” Van parking spaces are permitted to be 2440 mm (96 in) wide minimum where the adjacent access aisle is 2440 mm (96 in) wide minimum. Two accessible parking spaces may share a common access aisle. Parking access aisles must adjoin an accessible route to the facility and must comply with width and slope requirements for accessible routes.

- Access aisles must extend the full length of the parking spaces they serve.

- Access aisles must be marked to discourage parking in them.

- Accessible routes must connect parking spaces to accessible entrances. In parking facilities where the accessible route must cross vehicular traffic lanes, marked crossings enhance pedestrian safety, particularly for people using wheelchairs and other mobility aids. Where possible, it is preferable that the accessible route not pass behind parked vehicles.

- Accessible routes must have a minimum clear width of 915 mm (36 in) and no running slope greater than five percent.

- Parking spaces and access aisles must be level with surface slopes not exceeding two percent in all directions.

- The surface of all accessible routes must be stable, firm and slip resistant.

- Changes in the level of accessibility lanes up to 6 mm (¼ in) may be vertical and do not require edge treatment.

- Changes in level between 6 mm and 12 mm (¼ in and x ½ in) shall be beveled with a slope no greater than 1V:2H. Changes in level greater than 12 mm (½ in) require a bevel at the slope of 1V:12H.

- Parking spaces must be reserved for the disabled by a sign showing the symbol of accessibility. The signs must be visible, even when a vehicle is parked in the space.

9.4.6.5 Landscaping and Roadside Development

AASHTO defines roadside development as the treatment given to the roadside to conserve, enhance and effectively display the natural beauty of the landscape through which the highway passes.

Throughout the *Manual*, there are references to aesthetic considerations for incorporation into the final design. Aesthetic consideration is not something added onto the project at the last moment to make it look good. Owner agency input at an early stage is vital toward ensuring that all environmental concerns are satisfactorily incorporated into the final design.

Consider the highway as an essential element of the total environment, not as a separate entity apart from or in conflict with the environment. All highway-oriented disciplines should collaborate at all stages of the corridor selection, location and design. Only in this manner will the functional aspects of highway geometrics be an integral part of the aesthetic quality as it relates to the highway user and the immediate environment.

Employing as many of the landscaping treatments discussed in Section 9.4.6.5.1 as possible into the final design will enhance and emphasize the natural beauty of the roadside.

9.4.6.5.1 Landscape Treatment

In a rural environment, the most successful treatment is one that imitates the existing landscape elements. A motorist going 80 km/h (50 mph) is not going to see detailed landscape patterns. In parking areas (e.g., overlooks, vistas) (and, in some cases areas of slower moving traffic), a more concentrated effort is desirable to properly relate landscape details to the viewer.

The best landscape approach is one intended to completely eliminate change points by modifying vegetation clearing lines, cut slope lines and even ditch lines. Blend all treatments with existing or planted features to simulate natural forms.

The extent of landscape treatment will vary according to the amount of landscape manipulation and area visibility. The most visible areas should receive the greatest attention. Suggested possible treatments for these sites are plantings, slope molding and rock cut sculpturing, etc.

To achieve the necessary blending, concentrate the landscaping effort near the base of the fill and the top of the cut lines. When planting larger trees, specify them to be placed near the top of the cut slopes of the toe of the fill. Keep them beyond the clear zone and, if required, beyond the snow storage area in snow plowing areas.

On the higher speed rural roadways, plant groupings of one or two tree species can provide adequate treatment. More species diversity along with appropriate groundcover shrubbery is typical in urban planting situations.

9.4.6.5.2 Earthwork

Design cut-and-fill slopes not only to satisfy slope stability and balance material quantities but also to improve the appearance of the final project.

Use variable slope ratios for both cut and fill slopes. Avoid using constant slope ratios. The use of slope rounding at the top of cuts is commonplace. Round the ends of cuts and blend the ends of fills into the cut slopes.

When practical, include in the design some slope molding techniques to imitate the existing landscaping elements. Slope molding goes beyond variable slope and rounding concepts. With slope molding, a deliberate attempt is made to break up the uniformity of a finished slope.

On long cut slope faces, lay back the draws and accent the ridges. Warp slopes around existing large boulders and rock outcrops.

In areas of natural draws, lay back or flatten the cut slope to match that of the draw. This only generates a small amount of additional material and greatly enhances the appearance of the cut slope. This material can be used to flatten fill slopes or mold then into natural land forms common to the project area.

Accent ridges by steepening the slopes and rounding to the maximum extent practicable. Naturally, stable slopes are a basic consideration on any slope treatment so the steepening should not exceed Geotechnical recommendations.

On large cuts, the lay back the draws and accent the ridges technique may not work. The use of false draws and ridges to break up the slopes may be required, although this technique could cause a substantial increase in the roadway excavation unless the material is stable at relatively steep slopes.

9.4.6.5.3 Rock Work

On many projects with long, high rock slopes, the cooperating agencies may not permit presplitting along one face or along a number of benched faces. The demand is for a more natural appearing rock face that will be compatible with the natural existing rock faces in the area.

Rock cuts can be designed to produce a staggered bench effect, which will reflect natural terrain and accent natural fracture lines in the rock. When presplitting is necessary to stabilize the rock slopes, the use of staggered benches will break up the vertical drill scars.

Where slope stability is not a factor, non-presplit blasting techniques will expose the natural rock fractures. In some instances, this produces the most pleasing results.

Where practical, design planting pockets or benches in the slopes for the introduction of plant material. It is desirable to spread topsoil on all rock benches to encourage grass growth and minimize the visual scar through revegetation. The planting of trees and shrubs will aid in reducing the size and scale of the rock cuts.

9.4.6.5.4 Clearing Techniques

In heavily forested areas, usual clearing techniques may leave a vertical wall of vegetation at the tops of cuts and toes of fills. In these cases, selective thinning methods will produce a softer edge by cutting out taller old trees in favor of younger ones. The object is to produce a natural forest edge effect.

Selective thinning methods combined within scalloped clearing lines and vista clearing to promote and frame scenic views will enhance the natural beauty of any project. There is, however, a point where excessive clearing is not beneficial. In some areas, the emphasis should be on bringing the forest as close to the roadway as safety permits. A balance is needed that emphasizes vegetation patterns above and below the highway slope.

9.4.6.5.5 Revegetation

Revegetated slopes are not only pleasing to view but are stabilized and require little or no maintenance. Re-established vegetation is also important as cover and food for wildlife.

Select grass seed that is native to or adaptable to the area. The seed mixture should satisfy criteria for elevation and slope exposure changes. Several seed mixtures may be required to satisfy all conditions on a relatively long project. Use soil mulches and netting to stabilize and protect the ground until grass is established.

Where practical, conserve topsoil from the project limits and replace it on the finished slopes. The topsoil not only provides needed fertility and a growing medium for grasses, it contains an abundance of native seeds. These forbs, weeds and grasses usually grow fast and dense and will blend in with the undisturbed vegetation, which effectively brings the background vegetation onto the cut slope.

Shrubs and trees can be planted to primarily beautify the disturbed roadside areas and blend them into the undisturbed areas. Using hydrophilic shrubs (e.g., willow, birch) grouped in areas of excess soil moisture will aid in stabilizing the area. Locate all plant groupings in areas most visible to the motorist.

It is FHWA and FLHO policy that at least one-quarter of one percent of funds expended for landscape projects be used to plant native wildflowers, except in ornamental landscapes, or unless a waiver is granted by the Division Engineer.

An ornamental landscape is one that is irrigated, has barked shrub beds and has irrigated grass that is routinely mowed.

Requests for waivers can only be granted for the following conditions:

- wildflowers cannot be satisfactorily grown,
- the available right-of-way is to be used for agricultural purposes,
- there are no suitable available planting areas, and

- the planting poses a threat to endangered or rare plant species.

A waiver must be documented with adequate justification in support of all findings and conclusions.

Erosion control seeding is not a landscape item although wildflower seeding associated with the erosion control seeding mix can satisfy wildflower seeding requirements in a landscape project.

In order for wildflowers to perpetuate themselves, they must be permitted to go to seed and become dormant. Identify on the plans all areas to be seeded with wildflowers. Provide in the contract for the installation of suitable markers to identify the wildflower seed beds for roadside management and maintenance personnel.

9.4.6.5.6 Slope Treatment

This technique consists of placing boulders, stumps and old logs on cut-and-fill slopes to represent existing conditions beyond the clearing limits. These items are generally available on the project. Logs and stumps can be randomly staked to approximate a natural scattering on an adjacent slope. Boulders can be placed individually or in clusters. They are usually worked into the slopes to appear as natural outcroppings.